TELKOMNIKA, Vol.11, No.3, March 2013, pp. 1355 ~ 1362
ISSN: 2302-4046

Fault Diagnosis of Automobile Crane Power Steering System Aided by ICP-AES

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Abstract

The objective of this paper is to evaluate an innovative application of inductively coupled plasma atomic emission spectroscopy (ICP-AES) on the fault diagnosis of automobile crane hydraulic power steering (HPS) system. Contents of Fe, Cu and Al were examined by ICP-AES in the oil samples of HPS system for four different mileages of Puyuan QY50H. The mileages were 2000-9000 km, 11000-19000 km, 21000-28000 km and 32000-40000 km separately. Database of major mental contents in automobile crane HPS system of Puyuan QY50H with different mileage were calibrated. Results showed that, major mental contents were increased with the increasing of driving mileage and the normal contents laid between two trend lines. Through the determination of mental contents in HPS oil sample and further compared them with the values in their database, we could not only evaluate the wear condition of automobile crane HPS system, but also helped to diagnose the faults without dissembled the problematic vehicle. The results further indicated that, in time maintenance, high quality and low cost reparation could be realized by the application of ICP-AES technology on fault diagnosis of automobile crane power steering system.

Keywords: *ICP-AES; automobile crane; hydraulic power steering system; fault diagnose*

1. Introduction

Vehicle hydraulic power steering (HPS) system acquired the advantages of low energy consumption, sensitive response and flexible adjustment of power assisted steering according to different parameters such as steering angle and vehicle speed. It has been appeared to be the optimal choice for both passenger vehicle and engineering truck. However, except for helping to reduce steering operation fatigue, HPS system also exhibited some potential safety hazards like steering failure, hard steering and driving wandering etc. These faults are mainly caused by the pollution of particulate pollutants in power steering cylinder, distributing valve and metering valve. These pollutions may further lead to blind and wear of the system. Therefore it is of crucial importance to detect the oil polluted condition of vehicle hydraulic power steering system timely [1-4].

At present, methods concerning to the detection oil pollution in automobile crane hydraulic power steering system mainly focus on sensory examination such as visual inspection, touch and olfactory sensations. Regarding to the inspection of wear condition of steering distributing valve and metering valve, the detection is generally carried out in garages through dissembling, cleaning and further evaluating by eyes or special measuring tools to check whether to change the valves or not. In these detecting processes, the related methods not only require the vehicle to stop, but also can be detected only after the fault. Thus it is not possible to predict the faults before it happens through the traditional detecting methods. Moreover, steering valve, metering valve and steering slide valve are precise pairs, dissembling detection would decrease their practical working performance [5-7].

Inductively coupled plasma atomic emission spectroscopy (ICP-AES) is a new spectroscopic analysis method which adopt inductively coupled plasma torch as its laser source. Owing to the advantages combination of low detection limit, high accuracy and precision, fast analysis and wide linear range, it has grown to be one of the most popular analysis technologies and has been widely used in the detection of dozens of elements in environmental samples, rocks and minerals, biomedical samples, metal and alloy [8-10].

Received October 5, 2012; Revised January 13, 2013; Accepted January 24, 2013

The objective of this paper is to build a database for determination typical metal contents (Fe, Cu and Al) in different mileages of automobile crane HPS system oil samples in the same vehicle model to through the application of ICP-AES technology. Furthermore by figuring out the pattern between major metal contents and driving mileage, it was expected to monitor the wear condition of steering valve, metering valve, steering slide valve and other major parts in vehicle hydraulic power steering system. The results of this research were expected to predict the potential faults in HPS system and to provide foundation for maintenance and reparation of it and further to ensure the safety and security of the running automobile crane. In addition to that, by applying ICP-AES technology on the fault detection of automobile crane HPS system, detection method which can avoid the dissembling, decrease the repair cost and prolong its service life of automobile crane steering assembly was also anticipated with the result of this research.

2. Research Method

2.1. Instruments

IRIS Intrepid inductively coupled plasma atomic emission spectrometer (Thermo Electron Co., US); EXCEL Multi-function Microwave Chemistry Workstation (Shanghai EU Microwave Chemistry Technology Co. Ltd, China).

2.2. Reagents and Standard Solutions

Fe, Cu and Al standard solution (1.0 mg•mL^{-1}) were provided by Beijing NCS Analytical Instruments Co., Ltd. According to level of element inspiration difficulties and interference situation, different concentrations of standard blend solution were mixed: 0, 1, 5, 10 and 20 μg•ml^{-1}. Nitric acid was guarantee reagent (GR) and water was ultrapure water.

2.3. Sample Digestion Method

Samples source was HPS system oil sample of four different mileages of Puyuan QY50H. The mileages were 2000-9000 km, 11000-19000 km, 21000-28000 km and 32000-40000 km individually. Weighed 0.2 g oil samples separately and precisely, put them into the inner cup of digestion tank; added 5 ml concentrated nitric acid and stayed for one hour. Then put the digestion tank into microwave digestion system and digested it according to the process parameters listed in Table 1. Opened the digestion tank after it cooled down, the sample appeared as yellow transient solution, got rid of acid, and transferred it by ultrapure water to 25 ml, shook up before using. Sample in control test was prepared according to the same method.

Table 1. Optimal program of microwave digestion

Procedures	Temperature / ℃	Set Pressure / atm	Constant Temperature time / min
1	140	15	4
2	170	20	4
3	200	30	4

2.4. Instrument Operation Condition

Operation parameters of IRIS Intrepid were as follows: Radio-frequency power was 1050 kW; Pulverization pressure was 25 psi; Assisted air flow rate 1.0 L•min^{-1}; Sample washing time was 1 min; high wave scanning time was 5 s and low wave scanning was 30 s.

2.5. Instrument Operation Condition

According to the optimized instrument working condition, different concentration samples (0, 1, 5, 10 and 20 μg•ml^{-1}) were injected in turn and standard curves of different elements were plotted as shown in Figure 1-3.

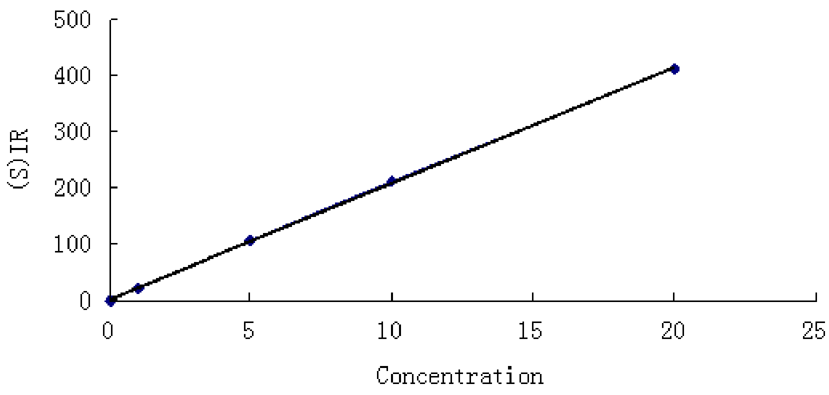

Figure 1. Standard Curve of Fe

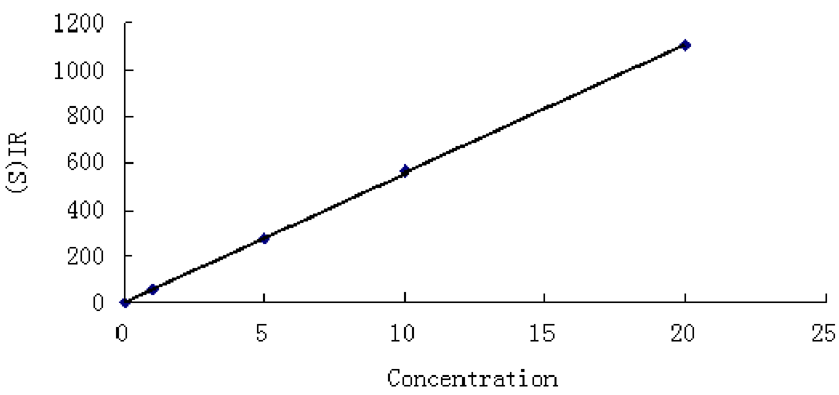

Figure 2. Standard Curve of Cu

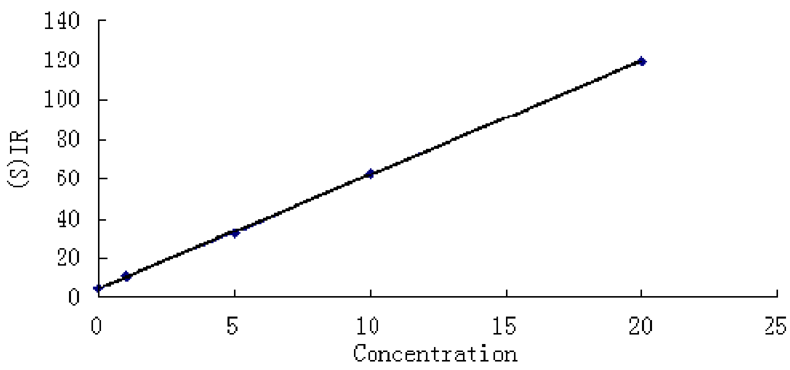

Figure 3. Standard Curve of Al

The standard curves of different elements were as follows: Fe: y=20.686x+1.7057; Cu: y=55.552x+2.0673; Al: y=5.7293x+5.0775. Linear correlation coefficients were all above 0.9998. Samples were analyzed according to the standard curves.

3. Results and Analysis
3.1. Elements Detection Limits
Under the optimized instrument working condition, digested blank solution was detected repeatedly (10 times) by ICP-AES technology, 3 times of results standard deviations were adopted as detection limits for different elements. As shown in Table 2.

Table 2. Detection limits of the method

Elements	Fe	Cu	Al
Wavelength/nm	259.9	324.7	308.2
Detection limits/μg·mL^{-1}	0.0012	0.0017	0.056

3.2. Recovery and precision test
The same oil sample (after digestion) was paralleled tested 6 times and relative standard deviation (RSD) was calculated. Standard addition method was adopted to examine the recoveries of different elements in respect to evaluate the accuracy of this method. Results were shown in Table 3. The results indicated that ICP-AES is a reliable and accurate method for quantitative analysis of elements contents in oil samples of HPS system.

Table 3. Results of recovery and precision test

Elements	Fe	Cu	Al
RSD/%	1.34	1.76	1.88
Average recovery/%	101.5	97.8	102.3

3.3. Sample determination results
According to the selected instrument working condition and analysis method, typical metal contents in steering oil samples of Buick Regal 2.4 with different mileages were tested. Results were listed in Table 4-6.

Table 4. Fe content in samples at different mileages

Mileages /1000km	Metal contents /μg • g^{-1}	Mileages /1000km	Metal contents /μg • g^{-1}
2	8.2	21	51.2
2	10.2	21	51.0
2	10.3	22	51.0
3	15.0	22	51.8
3	15.0	22	51.8
4	16.7	23	52.6
4	16.6	23	52.3
5	20.5	24	52.4
5	20.4	24	53.3
5	20.5	25	53.6
6	22.3	25	53.1
6	23.0	25	54.1
7	25.2	26	54.0
7	25.6	26	54.9
7	25.0	27	54.0
8	27.8	27	55.8
8	28.0	27	55.7
8	28.0	28	55.6
9	29.3	28	58.0
9	33.0	28	57.9
11	32.9	32	59.3
11	33.2	32	59.4
11	34.1	32	60.0
12	34.4	33	60.1
12	34.2	33	60.8

Continued Table 4. Fe content in samples at different mileages

Mileages /1000km	Metal contents /μg • g^{-1}	Mileages /1000km	Metal contents /μg • g^{-1}
13	35.3	33	61.3
13	35.4	34	61.5
13	35.1	34	61.4
14	36.6	35	62.4
14	37.3	35	62.2
15	41.6	36	63.1
16	43.5	36	63.1
16	44.8	37	63.8
16	45.2	38	64.5
17	47.2	38	64.9
17	47.3	38	64.1
18	47.5	39	66.1
18	48.3	39	65.8
19	48.3	40	66.7
19	48.2	40	66.4

Table 5. Cu content in samples at different mileages

Mileages /1000km	Metal contents /μg • g^{-1}	Mileages /1000km	Metal contents /μg • g^{-1}
2	1.6	21	11.2
2	1.7	21	11.1
2	1.8	22	11.3
3	2.1	22	11.5
3	2.1	22	11.5
4	2.3	23	11.9
4	3.1	23	12.1
5	3.2	24	12.0
5	3.2	24	12.3
5	3.3	25	12.4
6	4.2	25	12.9
6	4.6	25	12.9
7	4.9	26	13.4
7	4.9	26	14.1
7	4.6	27	14.9
8	5.2	27	15.8
8	5.6	27	16.3
8	5.7	28	15.8
9	5.9	28	16.4
9	5.8	28	16.2
11	6.8	32	16.3
11	7.0	32	16.2
11	7.4	32	16.4
12	7.1	33	16.5
12	7.2	33	16.3
13	7.8	33	16.8
13	7.8	34	16.9
13	8.1	34	17.4
14	8.2	35	17.3
14	8.5	35	17.6
15	8.5	36	18.1
16	8.8	36	18.2
16	9.4	37	18.4
16	9.1	38	18.6
17	9.9	38	18.4
17	9.9	38	18.9
18	9.7	39	19.2
18	10	39	19.1
19	9.8	40	19.5
19	10.1	40	19.5

Table 6. Al content in samples at different mileages

Mileages /1000km	Metal contents /μg • g^{-1}	Mileages /1000km	Metal contents /μg • g^{-1}
2	25.1	21	62.4
2	26.3	21	62.1
2	30.5	22	61.9
3	30.2	22	62.9
3	31.9	22	66.5
4	33.7	23	67.5
4	33.4	23	67.9
5	33.0	24	67.5
5	35.6	24	68.9
5	35.8	25	69.5
6	38.2	25	70.6
6	38.7	25	70.5
7	37.9	26	71.1
7	39.4	26	72.2
7	39.1	27	72.6
8	42.1	27	73.8
8	41.8	27	74.1
8	43.5	28	74.3
9	46.2	28	75.6
9	45.7	28	75.8
11	48.4	32	77.4
11	47.6	32	77.6
11	48.6	32	78.2
12	48.9	33	78.6
12	48.7	33	78.4
13	49.1	33	79.9
13	48.7	34	79.6
13	49.2	34	79.3
14	51.2	35	80.7
14	51.7	35	80.4
15	54.3	36	81.0
16	55.1	36	80.7
16	55.7	37	81.1
16	54.7	38	81.4
17	56.4	38	81.2
17	57.3	38	81.1
18	59.1	39	83.1
18	58.7	39	83.3
19	60.1	40	83.5
19	60.7	40	83.9

3.4. Results Analysis

Statistically analysis to the results of former tests showed that, the contents of Fe, Cu and Al in steering oil samples were related to the mileage to a certain extent as shown in Figure 4.

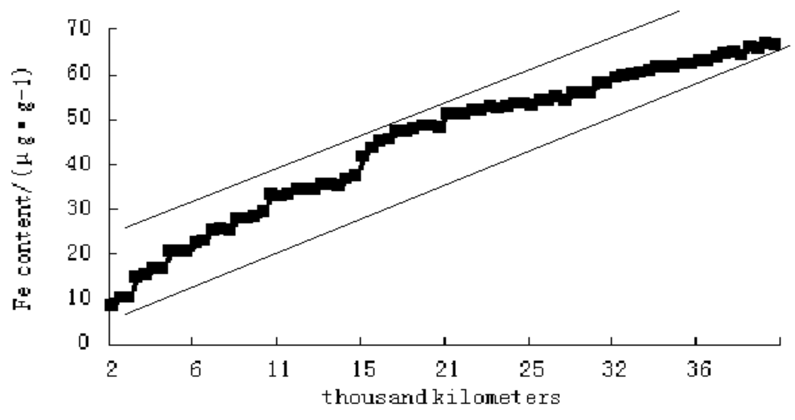

Figure 4. Mileage trend of iron content in the power-steering fluid

We can inferred from Figure 4 that, Fe contents in oil samples were increased with the increasing of mileage, and different mileages Fe contents were restricted in the range of two standard linear curves.

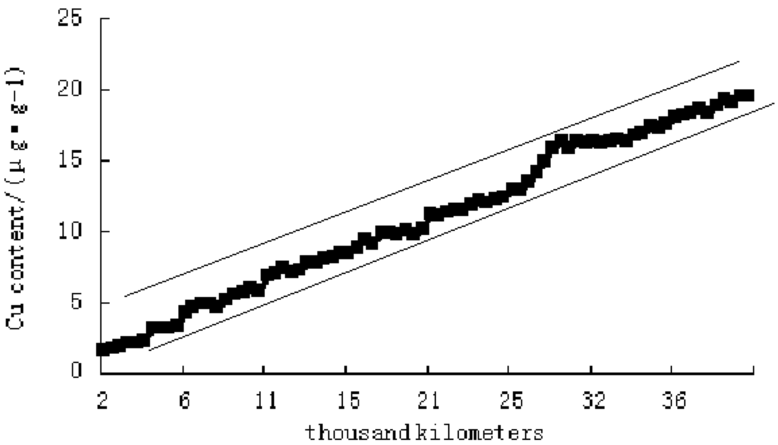

Figure 5. Mileage trend of copper content in the power-steering fluid

We can inferred from Figure 5 that, Cu contents in oil samples were increased with the increasing of mileage, and different mileages Cu contents were restricted in the range of two standard linear curves.

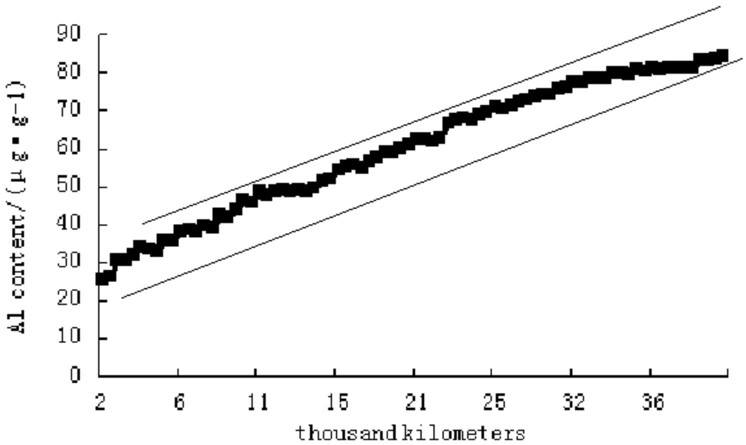

Figure 6. Mileage trend of aluminum content in the power-steering fluid

We can inferred from Figure 6 that, Al contents in oil samples were increased with the increasing of mileage, and different mileages Al contents were restricted in the range of two standard linear curves.

4. Demonstration test

The research results was demonstrated on a Puyuan QY50H automobile crane with a mileage of 28000 km. Steering heavy was appeared according to the driver reflection. Firstly we speculated that this phenomenon could be the signal of severe wear of the control valve in hydraulic power steering system, and impurities existed in power steering oil. Typical metal contents in the oil were determined through ICP-AES technology: contents of Fe were 66.5 $\mu g \cdot g^{-1}$; Cu was 20.5 $\mu g \cdot g^{-1}$ and Al was 86.7$\mu g \cdot g^{-1}$. Compared them with the results in Figure 4-6, we confirmed this phenomenon as the severe wear of the control valve in hydraulic power steering system preliminarily. By the dissembling of control valve, we found that control slide valve and valve body were severely worn. The actual situation confirmed our speculation. By replacing it to the new valve, the fault disappeared.

The results of this paper indicated that, ICP-AES technology is a promising analytical method for the determination of typical metal contents in the oil of automobile crane power steering system. By the determination of major metal contents, we realized the evaluation of wearing condition of the concerning valves and further reached the objective of fault diagnose of automobile crane power steering system.

Acknowledgement

This paper was funded by “2013 Public Welfare Project of Zhejiang Province”.

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